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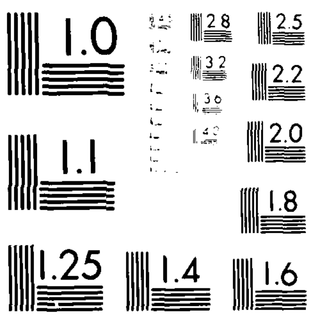


MICROCOPY RESOLUTION TEST CHART

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TECHNICAL REPORT GL-84-6

# ENGINEERING CRITERIA FOR USE OF GEOTEXTILE FABRICS IN PAVEMENT AND RAILROAD CONSTRUCTION

by

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Available literature concerning the use of geotextiles as separator mechanisms between granular and subgrade materials used in the construction of roadways and railroads is presented. Procedures and results of tests using a model load cart with a rolling wheel load to evaluate geotextiles are also presented. The model load cart provides a fast and excellent means of applying a large number of traffic cycles to an aggregate geotextile

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20. ABSTRACT (Continued).

subgrade system in a short period of time.

Criteria for selecting geotextiles to be used in road and railroad construction by the U. S. Army Corps of Engineers are analyzed. A separator mechanism is generally provided between layers in the pavement system for low-volume trafficked short lifetime roadways of any geotextile, but a nonwoven, needle-punched, polyester fabric is required for long-term, high-volume usage. The fabric can weigh a minimum of 4 oz/sq yd and can transmit water laterally. Geotextiles used in railroad construction can be placed 10-12 in. below the bottom of railroad ties to minimize abrasive damage caused by full depth tamping.

# PREFACE

The investigation reported herein was sponsored by the Office, Chief of Engineers (OCE), U. S. Army, Facilities Investigation and Studies (FIS) Program Work Effort.

The study was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) from January through August 1983 by the Pavement Systems Division (PSD) of the Geotechnical Laboratory (GL). Personnel of the PSD involved in this study were Messrs. S. G. Tucker, H. L. Green, H. H. Ulery, G. L. Carr, and Dr. W. R. Barker. The study was conducted by Messrs. R. H. Grau and H. G. Brown, PSD. The report was written by Mr. Grau.

The work was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL, and under the direct supervision of Dr. T. D. White, Chief, PSD, GL.

The Commander and Director of WES during the study and preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

## CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

*U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:*

| Multiply | By | To Obtain |
|---|---|---|
| inches | 25.4 | millimetres |
| mils | 0.0254 | millimetres |
| ounces per square yard | 0.03390575 | kilograms per square metre |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per inch | 175.1268 | newtons per metre |
| pounds (force) per square inch | 6894.757 | pascals |
| pounds (mass) | 0.4535924 | kilograms |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic metre |
| pounds per square yard | 0.542492 | kilograms per square metre |
| square inches | 6.4516 | square centimetres |
| tons (2000 pounds, mass) | 907.1847 | kilograms |

# ENGINEERING CRITERIA FOR USE OF GEOTEXTILE FABRICS IN PAVEMENT AND RAILROAD CONSTRUCTION

## PART I: INTRODUCTION

### Background

1. Woven and nonwoven geotextiles are now being used in many civil engineering applications. New manufacturing processes produce a wide range of fabrics with structures and characteristics that make them particularly suitable in these practices. In recent studies, the operational functions of geotextiles used in various soil systems have been identified. McGowan and Ozelton (1973) determined that geotextiles had three basic operational functions: separation, filtration, and reinforcement. Leflaive and Puig (1974) recognized a fourth function--drainage in the plane of thick nonwoven fabrics. The reinforcement function has been subdivided into two additional functions. Steward, Williamson, and Mohney (1977) defined lateral restraint of cohesionless soils as a special category of reinforcement, and Kinney and Barenberg (1979) described membrane support as a second category of reinforcement.

2. In recent years, geotextiles have been used in roadway and railroad construction as a separation medium. Separation is a physical process of preventing two dissimilar materials from mixing. As separators, geotextiles are placed between aggregate layers and soil subgrades during construction of roadways to prevent intrusion of granular material into the subgrade and to stop migration of fine soil subgrade particles into the base course. Geotextiles are used in new railroad construction to separate ballast or subballast from the subgrade, and the primary purpose of a geotextile used for track rehabilitation is to prevent fines from the subgrade, subballast, or dirty ballast below the undercutting elevation from fouling cleaned or new ballast (Raymond 1982).

### Scope and Purpose

3. This report includes a brief discussion of the various manufacturing processes of geotextiles and a summary of a literature review of available

information concerning the use of geotextiles as separators in roadway and railroad construction. Tests were conducted with a small pneumatic-tired testing apparatus used to evaluate aggregate/geotextile/subgrade systems. The test apparatus is described and results of the tests are reported herein. Information obtained during this investigation is used to recommend criteria for selecting geotextiles used as separators in roadway and railroad construction.

## Definitions of Terms

4. Several special terms used in this report are defined below for the reader's convenience:

Denier--the weight in grams of 9000 m of fiber or yarn.

Equivalent Opening Size (EOS)--the number of the U. S. Standard sieve having openings closest in size to the filter fabric openings. EOS is expressed as a U. S. Standard sieve number.

$D_{85}$--size of pores in a fabric of which 85 percent is this size or finer.

Rut--a track worn by a wheel. The rut depth is measured from the original surface to the lowest point of deformation.

Tenacity--the tensile stress expressed as force per unit linear density of the unstrained specimen.

Yarn--a generic term for a continuous strand of textile fibers, filaments, or material in a form suitable for knitting, weaving, or otherwise intertwining to form a textile fabric.

## PART II: MANUFACTURE OF GEOTEXTILES

5. According to the American Society for Testing and Materials Subcommittee on Geotextiles and Geotextile Applications, a geotextile is defined as any permeable textile material used with foundation, soil, rock, earth, or any geotechnical engineering-related material that is an integral part of a man-made project, structure, or system (Giroud and Caroll 1983). A large selection of geotextile products have been made commercially available during the last 10 years. The synthetic fiber composition of geotextiles is generally polyethylene, nylon, polypropylene, or polyester. Polypropylene and polyester are the most common. Geotextiles are available in two basic types of construction--woven and nonwoven.

### Synthetic Fibers

6. Most synthetic fibers are formed by forcing a syrupy substance through holes of a spinneret. The original state of the fiber-forming substance is a solid that is converted to a liquid by heat or chemicals before it is extruded through the spinneret. The fibers can be extruded in different thicknesses, measured in deniers. For comparison purposes, women's sheer nylon stockings are commonly made from 15-denier monofilament, and automobile tires are made with 840-denier fibers.

### Woven Fabrics

7. Woven geotextiles are formed on a loom by a system of lengthwise-interlocking (warp) and crosswise-interlocking (fill) yarns. All woven geotextiles are developed from one of three fundamental patterns--plain, twill, or satin. The physical properties of woven fabrics, such as, strength, permeability, weight, and stiffness, can be varied by altering the basic weave pattern or the number of yarns per inch (count) used in the construction of the fabric. Woven fabrics generally have higher strengths at lower elongations than nonwoven fabrics. The strengths are unequal in the warp and fill directions.

### Nonwoven Fabrics

8. The majority of nonwoven fabrics used in civil engineering

construction are manufactured by needle punching, spun bonding, melt bonding, and resin bonding processes. Brief descriptions of these processes are as follows:

a. Needle-punched fabrics are produced by forcing barbed needles repeatedly through a fibrous web of continuous or staple fibers. This causes a thorough intermixed mechanical bond among the individual fibers. Thick geotextiles (greater than 0.040 in.*) are produced by the needle-punched process.

b. Spun- and melt-bonded fabrics are produced in essentially the same manner. Continuous filaments are laid on a conveyor belt to form a continuous web. Orientation of the filaments is varied to provide desired fabric characteristics, and then the filaments are bonded together to form a fabric. The monofilaments of spun-bonded fabrics are bonded by thermal, mechanical, or chemical treatment. In the melt-bonded process, a continuous web is formed with either monofilaments or heterofilaments. Heterofilaments are continuous filaments that comprise a center core of one material and an outer sheath of a different material. When only monofilaments make up the web, filaments with different melting characteristics are used. Therefore, only some of the filaments are thermally melt-bonded at their cross-over points to form a fabric. When heterofilaments form the web, only the outer sheaths of the filaments melt and bond together when heat is applied.

c. Fabrics produced by the resin-bonded process are usually formed by spraying or impregnating fibrous webs with an acrylic resin. After the resin is cured, a strong bond is formed between filaments.

9. Nonwoven geotextiles are characterized as having equal strength properties in all directions. This is due to the random placement of the filaments that make up the geotextiles. When compared with woven fabrics, nonwoven fabric strengths are less and their elongations are greater. Nonwoven geotextiles exhibit a wide range of pore sizes which makes them effective as soil filters. Some of the geotextiles have high planar permeability which is required for rapid release of pore pressures and lateral removal of water from an area or surface. A more in-depth description and discussion of geotextile fabrication can be found in Koerner (1980) and Rankilor (1981).

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is given on page 3.

# PART III: LITERATURE REVIEW

## Geotextiles Used in Roadway Construction

### General roadway structure design

10. Conventional road designs are based on decreasing applied vehicle wheel loads on soil subgrades which are not capable of withstanding the loads without failure. Such a decrease is accomplished by placing a layer of strong granular material, i.e., a base course, between the vehicle wheels and the subgrade. In cases where the required thickness or distance between the wheels and subgrade is large, a subbase is placed between the base course and the subgrade. The subbase consists of a material that is stronger than the subgrade, yet weaker than the base course. Granular base course and subbase materials decrease applied vehicle wheel loads on subgrades by distributing the loads over a larger area of the subgrade.

11. The bearing strength of an aggregate layer is developed by frictional contact between individual particles of aggregate. A maximum frictional force can only be developed if the particles are (a) clean, (b) in firm contact with each other, (c) angular in shape, and (d) well graded. The design thickness of an aggregate layer required for a roadway is based on the bearing strength of the subgrade, the bearing strength of the subbase and/or base course, and the expected types, loadings, and number of vehicles that will traffic the roadway.

### Geotextiles used as separators

12. One of the most common uses of geotextiles in road construction is to provide separation between subgrades and granular materials. Where wet, low-strength subgrade conditions prevail, geotextiles are placed between the subgrade soils and aggregate layers to prevent or minimize the intermixing of the two materials during and after construction. When approximately 20 percent by weight of a fine-grained subgrade soil is mixed into a dense-graded base course, the bearing capacity of the contaminated base course is reduced to that of the subgrade (Yoder and Witczak 1975).

13. The actual design thickness of an aggregate layer is difficult to achieve during construction of a roadway unless some medium is used to separate the aggregate from the subgrade. If the two materials are not separated, some of the aggregate particles will be pushed into the subgrade as the

aggregate is placed and compacted. When this occurs, aggregate is dispersed from the main body of the granular material and the design thickness is essentially reduced. The aggregate particles that are embedded into the subgrade lose their useful frictional function because they are no longer in direct contact with each other. When fine-grained subgrade soil particles are allowed to migrate into an aggregate base course, the useful aggregate thickness is also reduced. This occurs during trafficking as mud is pumped upward. The useful thickness is reduced because the wet, fine-grained particles (mud) lubricate the faces of the aggregate, and then the maximum frictional forces between the aggregate particles are reduced. When frictional forces are reduced, the shear strength and stability of the coarse-grained aggregate material are also reduced. Additionally, the introduction of fine-grained materials into the aggregate voids reduces the drainage capability of the aggregate.

### Investigations of geotextiles used as separators

14. Various regional offices of the U. S. Forest Service have installed test sections of geotextiles on low-volume roads. One test section was located in the Quinalt National Forest, Washington. As reported by Steward, Williamson, and Mohney (1977), seven nonwoven geotextiles were placed on the test road in an area where the subgrade strength was less than 0.1 California bearing ratio (CBR) and the water table was at ground level. The geotextiles, which ranged in weight from 4 to 12.4 oz/sq yd, were placed on the subgrade and then overlaid with aggregate. The test sections were designed in accordance with procedures recommended by Barenberg, Dowland, and Hales (1975). Data were collected with settlement plates, strain gages, and pressure cells. After the tests sections were trafficked by logging trucks, results of the collected data showed that settlement occurred rapidly to about 6 in., and the strain gages measured no strain in the fabric. The absence of strain indicated that the geotextiles were performing as separators without contributing to the strength of the roadway system. Results also indicated that the lightweight fabrics were as puncture resistant as the heavy fabrics. Physical properties which control the performance of geotextiles under field conditions have not been established by the Forest Service since it is using geotextiles on a trial basis.

15. McGowan and Ozelton (1973) discussed the performances of three nonwoven, melt-bonded, heterofilament fabrics used as separators in the

construction of a haul road located at a quarry. Weights of the fabrics ranged from 5.7 to 11.4 oz/sq yd and the equivalent opening size (EOS) of each was 120. The fabrics were placed on a soft clay subgrade and overlaid with fragmented quartz aggregate to a minimum depth of 14 in. After 40,000 tons of quarry stone had been transported over the road, no detectable differences in the performance of the three fabrics were observed.

16. Bell, McCullough, and Snaith (1982) discussed the function of separation provided by geotextiles in an aggregate/geotextile/subgrade system. Basically, subgrade pumping and subgrade intrusion must be alleviated if the separation function is maintained. Pumping occurs when: (a) high stresses are developed at the subgrade/aggregate interface, (b) free water is present, and (c) the aggregate layer is open to permit subgrade fines to enter the aggregate. Bell et al. pointed out that, although many installations of geotextiles effectively prevent subgrade pumping, theories concerning the influence of geotextiles on pumping and the geotextile properties required to prevent pumping are not well developed. Bell et al. stated that in order for a geotextile to prevent subgrade intrusion, the geotextile must not be punctured. Important properties related to the prevention of intrusion include: (a) pore characteristics, (b) friction, (c) strength, (d) puncture resistance, and (e) abrasion resistance.

17. Laboratory tests were conducted by Bell, McCullough, and Snaith (1982) to investigate the use of geotextiles and granular filters designed to prevent migration of clay fines from subgrades into overlying granular layers. Results indicated that for both types of filters contamination was dependent on their pore size characteristics. The best performing granular filter and geotextile conformed to the piping criteria as follows:

$$\text{Granular:} \quad \frac{D_{15}\ (\text{filter})}{D_{85}\ (\text{soil})} \leq 5$$

$$\text{Geotextile:} \quad \frac{D_{85}\ (\text{filter})}{D_{85}\ (\text{soil})} \leq 1$$

A thick, nonwoven geotextile with good load-spreading ability and cross-plane permeability was suggested for use as a separator.

18. Based on limited field performance observations and laboratory tests of a limited number of available geotextiles, the Department of the Army, Corps

of Engineers (CE) (1977) published a guide specification for the procurement and installation of plastic filter fabric. In general, the specification states that a fabric should be selected that retains the soil, yet has openings in the fabric large enough to permit drainage and prevent clogging. This guide specifies that when a fabric is placed adjacent to granular materials containing 50 percent or less by weight of fines (minus No. 200 material), the $D_{85}$ of the soil shall be greater than or equal to the EOS of the fabric. However, when a fabric is placed adjacent to all other soil types, the EOS of the fabric shall be no larger than the openings in the U. S. Standard Sieve No. 70. The guide also suggests that in order to reduce the chance of clogging, no fabric with an EOS smaller than 100 should be specified, and filter fabrics should not be used for soils with 85 percent or more particles smaller than the No. 200 sieve.

19. Haliburton, Lawmaster, and King (1980) conducted tests to evaluate the separation performance of four geotextiles. The tests were designed to simulate an aggregate/geotextile/subgrade system subjected to a rocking load which might approximate the effects of vehicle wheel loads during traffic. The geotextiles represented a wide range of commercially available fabrics, i.e., needle-punched nonwoven, heat-bonded nonwoven, split-tape woven, and multifilament woven. A kaolinite clay was used as the subgrade, and 0.5-in.-diam steel ball bearings simulated the aggregate. Performance of each geotextile was determined by measuring the vertical displacement of the load plate during the tests. These displacements were compared with results obtained in tests conducted on an aggregate/subgrade system which had no geotextile separator. Short-term performance of the fabrics could be determined since only 200 cycles of the rocking load were applied to each system. Results indicated a marked increase in deformation resistance of the geotextile systems as compared with the nongeotextile systems. All four geotextiles performed essentially the same. Conclusions were that all types of geotextiles can provide short-term separation of cohesive subgrades and cohesionless aggregates.

## Geotextiles Used in Railway Construction

20. The stabilization of railroad track is always a problem, and heavier axle loads, increased traffic speeds, and longer trains intensify the problem by accelerating the deterioration of subgrades and ballast. Newby (1982)

describes subgrade reaction to railroad traffic which produces both high-magnitude cyclic and direct vibratory loads onto rails that rest on crossties. Since ballast is compacted only under each rail during construction and loads are concentrated primarily under each rail during traffic, a nonuniform distribution of loads is applied to the subgrade. This condition, along with varying subgrade materials and heavy traffic tonnage, causes deformation of the subgrade to vary in depth. Thus, rainwater that flows through the open-graded ballast and ponds in the subgrade deformations results in a completely saturated soil with free water. High instantaneous pore pressures develop in the saturated subgrade when repeated traffic loads are applied, and the subgrade goes into a plastic state if the pore pressures are not dissipated rapidly. When this condition occurs, the subgrade develops a low bearing strength, ballast penetrates into the subgrade, and subgrade fines migrate upward into the voids of the ballast. Eventually, the bearing capacity of the track structure decreases and track failure occurs. Failure is caused when the initial depth of the ballast decreases as the ballast is forced into the subgrade, and the ballast shear strength decreases as individual pieces of ballast are lubricated with the fines that migrated upward from the subgrade.

### Investigations of geotextiles used as separators

21. Nichelson, Brozio, and Benson (1978) reported the condition of several sites where various geotextiles were installed at grade crossing on mainline railways. These sites had previous histories of subgrade pumping problems. The geotextiles installed at the crossings were manufactured from either woven polypropylene monofilament yarns or spun-bonded polypropylene continuous filaments. Each fabric weighed approximately 4-1/2 oz/sq yd. These fabrics were placed beneath the bottoms of ties to depths that ranged from 5-1/2 to 12-1/2 in., and had been in service for periods of 2 to 6 years. At one of the sites, the surface drainage was very poor, and water was found in the bottom 3 in. of ballast. Investigation of the sites revealed that there was no evidence of subgrade pumping, the subgrade fines had not migrated into the ballast above the fabrics, and the fabrics had not been overstressed or damaged.

22. Nichelson, Brozio, and Benson concluded that both woven and nonwoven fabrics performed satisfactorily and suggested guidelines for geotextiles used at railroad crossings as follows:

| Property | Requirements |
| --- | --- |
| Weight, oz/sq yd, ASTM D 1910 | 4 minimum |
| Grab tensile strength, lb, ASTM D 1682 | 90 minimum |
| Elongation at break, percent, ASTM D 1682 | 25 minimum |
| EOS, U. S. Sieve No. | 70 maximum |

23. Newby (1980) discussed results of field tests conducted on different weights of heat-bonded and needle-punched polypropylene and needle-punched polyester geotextiles used to stabilize subgrades beneath railway track. These tests were conducted during a period of 5 years on low-strength clay subgrades. Both needle-punched fabrics showed good filtration characteristics and allowed water to flow laterally through them much better than the woven or heat-bonded fabrics. The woven and heat-bonded fabrics were more susceptible to plugging by soil particles. Less subgrade deformation was observed in areas where polyester fabrics were used; this indicates that the polyester fabrics provided greater tensile reinforcement. The polyester fabrics were highly resistant to ultraviolet rays, but polypropylene fabrics were not. Resistance to ultraviolet rays is important because rolls of fabric are often left in storage yards where they are exposed to sunlight, or installed fabrics are exposed to sunlight because delivery of ballast is delayed.

24. Raymond, Purdy, and Gerry (1982) investigated 16 railroad rehabilitation sites where geotextiles had been placed under new or cleaned ballast. The geotextiles had been in service for periods that ranged from 3 to 5 years. The majority of the test sites were located in poorly drained, flat marshy areas. These investigations included both visual observations of each site and laboratory testing of geotextile samples obtained from each site. Conclusions resulting from these investigations were as follows:

- a. The needle-punched nonwoven geotextiles provided the best lateral drainage.
- b. Heavy, well-needle-punched geotextiles with EOS values of 400 or less resisted clogging better than the lighter needle-punched or heat-bonded fabrics. When clogging occurred, soil particles became trapped within the internal fibers of the structure and caused abrasion of the fibers and reduced the permeability of the geotextile.
- c. Monofilament woven and heat-bonded nonwoven geotextiles could not adequately conduct water in the plane of the geotextile.

d. For geotextiles used in track rehabilitation, tensile strength is secondary to impact and abrasion-resistant characteristics.

e. Needle-punched nonwoven geotextiles dipped in synthetic resins and forced-air-dried showed superior resistance to abrasion and impact.

f. Geotextiles placed 10 in. or more below the bottom of the ties showed marked reduction in abrasive damage.

g. Ultraviolet light damage was evident for the geotextiles that were fabricated from nonpolyester polymers.

25. Suggested guidelines for geotextile specifications based on results of the above authors' investigations are as follows:

| Property | Requirements |
|---|---|
| Weight, oz/sq yd | 10 if used below the ties of continuous welded rail track; 29 if used below rail joints, switches, or diamonds |
| Residual binder, percent by weight | 5-15 |
| Polymer | Polyester |
| EOS, U. S. Sieve No. | 400 maximum |
| Manufacturing process | Needle-punched, resin-dipped, forced-air-dried |
| Abrasion resistance | Less than 50 percent loss in modulus after 1000 cycles of H-18 stone, 1000 g, Tabor Abrador |
| Tensile strength | No requirements; if the geotextile can meet the abrasion and impact requirements, it will have sufficient strength |

26. Newby (1982) discussed the effects of geotextiles used for railroad subgrade stabilization and listed certain criteria that geotextiles must meet. His discussion was based on (a) tests of geotextiles that were begun in 1975, (b) results of tests of a highly instrumented railway test site constructed in 1977, and (c) the installation and subsequent observation of over 1000 miles of railroad track structure in which geotextiles were used. Newby considered separation, filtration, and planar permeability for rapid release of pore pressures to be as important as tensile strength when selecting a geotextile for stabilizing a railroad subgrade. He also determined that full-depth tamping would not affect geotextiles if the depth of cover below the crossties was 12 in. or more.

27. Typical physical characteristics or requirements, such as, tensile strength and tear strength, were not included in Newby's geotextile specifications because he did not consider the standard fabric tests applicable to geotextiles. He suggested that new tests which simulate field conditions be developed and adopted as standard. Newby suggested that new geotextile tests specify that the test specimens be saturated with water prior to testing since all geotextiles inspected under field conditions were saturated.

28. Geotextile specifications based on Newby's years of experience are listed as follows:

| Property | Requirements |
| --- | --- |
| Weight | None specified; requirements depend on type of soil subgrade, rainfall, and traffic tonnage |
| Polymer | Polyester |
| Manufacturing process | Nonwoven, needle-punched |
| Elongation, percent | 60-100 |
| Filament size, deniers | 9 |
| Fiber length, in. | 6 minimum |
| Tenacity, g/denier | 4 |

29. Results of long-term investigations of geotextiles used as separator mechanisms in railroad construction indicated that staple fiber nonwoven fabrics and thin, rigid nonwoven fabrics were unsuitable (Brandl 1982). Failure of these geotextiles was caused by fatigue of the chemical bonds in the staple fiber fabric and mechanical damage of the thermal bonds in the thin, rigid fabrics. Only geotextiles fabricated with continuous fibers that were mechanically bonded performed satisfactorily during the 9-year test period. Brandl concluded that low-stretch geotextiles should be protected with a thin layer of coarse sand so the sharp edges of ballast would not perforate geotextiles when the ballast is tamped.

### Development of laboratory test procedures

30. There is a definite need to establish standard laboratory tests and procedures to evaluate geotextiles used in railroad construction. Currently, the physical properties of geotextiles are determined by test methods that were developed to test fabrics used for purposes other than geotextile

applications. There is also a problem in that all manufacturers do not use the same test method to determine a specific property. When different test methods are used or procedures of one method are altered, drastic variations in the results can be obtained. New laboratory tests and procedures must duplicate actual field conditions where fabrics are to be used so properties relevant to fabric use can be evaluated.

31. Laboratory tests are being developed at the Joint Association of American Railroads (AAR)/Illinois Institute of Technology Soils Laboratory in Chicago, Ill., which are designed to evaluate ballast/soil/fabric interactive mechanisms (Leshchinsky 1982). These tests are also designed to duplicate actual field conditions. When the laboratory test program is completed, test details and specifications will be issued by the Track Research Division, Research and Test Department, of the AAR. Three tests that have been developed are described in the following paragraphs.

32. A filtration/separation test was developed that measures (a) the amount of subgrade fines which pass through a geotextile and (b) the permanent deformation of a ballast/soil/fabric system after a cyclic load is applied to the system. The test is performed on a 12-in.-diam sample contained in a smooth-walled plexiglass cylinder. The lower part of the sample is compacted soil and the upper part is ballast. The soil-ballast interface is separated with a geotextile. The sample is submerged in water for one week before a cyclic load is applied. The results of this test can be evaluated through the concept of track geometry deterioration since deterioration is related to differential permanent settlement along a track.

33. A direct shear test was developed to evaluate a geotextile's tensile strength and assess the potential lateral restraint that can be achieved by the geotextile. The test apparatus consists of two large shear boxes that can be moved with respect to each other. The lower box is filled with compacted soil and the upper box contains ballast. The test specimen is placed between the two boxes. Stress normal to the shear surface can be controlled to simulate vertical stresses that are induced from the bottom of a tie onto a fabric-soil interface. Maximum shear stresses are measured between the ballast and geotextile. A geotextile's minimum required tensile strength for a specific field condition can be determined from the results of this test. An indication of the relative lateral restraining ability of a geotextile can also be determined.

34. Geotextiles are exposed to high loads and may be punctured or severely abraded when ballast is tamped. A puncture resistance test was developed to simulate the action of tamper blades on geotextiles. The tamping action is simulated by using a direct shear box that contains soil in the bottom half and a 2-in. layer of ballast in the upper half. A geotextile separates the ballast from the soil and a vertical load is applied to the ballast with a small-diameter piston. Both static and cyclic loads are applied with the piston. Puncture resistance of a geotextile is determined when the static load is applied, and abrasion resistance is determined when the cyclic load is applied.

## Summary of Literature Review

35. The findings of the literature review concerning the use of geotextiles in roadway construction are summarized below:

- a. Lightweight (4 oz/sq yd) nonwoven geotextiles are adequate for providing separation when used on low-volume roads trafficked with log trucks.
- b. The U. S. Forest Service has not established physical properties of geotextiles which control the performance of geotextiles used in field conditions.
- c. Nonwoven, melt-bonded, heterofilament geotextiles that weigh 5.7 oz/sq yd and possess an EOS of 120 provide adequate separation for haul roads located at quarries.
- d. Important geotextile properties related to the prevention of subgrade intrusion are: pore characteristics, friction resistance, strength, puncture resistance, and abrasion resistance.
- e. Thick, nonwoven geotextiles with good load-spreading ability and lateral permeability should be used as separators.
- f. Both nonwoven and woven geotextiles provide short-term separation between aggregate and subgrade materials.

36. The findings of the literature review concerning the use of geotextiles in railroad construction are summarized below:

- a. Both woven and nonwoven geotextiles perform satisfactorily when used as separators in the construction of railroad crossings.
- b. Suggested minimum properties for geotextiles are as follows: (1) weight, 4 oz/sq yd; (2) grab tensile strength, 90 lb.; (3) elongation at break, 25 percent; and (4) EOS, 70.
- c. Needle-punched nonwoven fabrics provide better filtration and lateral permeability characteristics than woven or heat-bonded fabrics.

_d_. Polyester fabrics are resistant to ultraviolet rays, but polypropylene fabrics are not.

_e_. A maximum EOS value of 400 is required for geotextiles used as separators.

_f_. The tensile strength of a geotextile is secondary to its impact and abrasive resistant characteristics.

_g_. Resin-dipped needle-punched fabrics are more resistant to abrasion and impact than nonresin-dipped fabrics.

_h_. Abrasive damage of geotextiles caused by full-depth tamping is minimized when geotextiles are placed 10 to 12 in. below the bottom of ties.

_i_. The minimum weight of fabrics placed under joints, switches, and diamonds should be 29 oz/sq yd.

_j_. A geotextile should have the ability to hydraulically conduct water in the plane of the geotextile.

_k_. Geotextiles fabricated from mechanically bonded continuous fibers provide better separation than do chemically or thermally bonded staple fiber fabrics.

_l_. There is a definite need to establish standard laboratory tests and procedures for evaluating geotextiles.

## PART IV: LABORATORY STUDY

37. Laboratory investigations were conducted at WES to determine factors that affect the performance of geotextiles used as separator mechanisms between granular base course and fine-grained subgrade materials. Tests were designed to evaluate geotextiles included in permanent pavement systems. Factors such as rut development, aggregate penetration into the subgrade, and fine subgrade particle migration into aggregate base courses were observed and reported as a small load wheel trafficked on prepared test sections. Four geotextiles manufactured by different processes were selected for testing. Due to unexpected problems such as excessive movement of aggregate particles in the base course and equipment malfunction, financial resources permitted the testing of only one geotextile.

### Development of Test Parameters

38. Laboratory tests were designed to simulate a permanent pavement system in which the surface of the soil subgrade was soaked with water. An arbitrary pass level of 10,000 was selected to represent the amount of traffic desired to pass over the pavement system before it failed. Since pavement failure is basically caused by stresses applied to the subgrade, and these stresses are a result of wheel load, tire pressure, and distance between the load wheel and the subgrade, a thickness of cover was calculated to decrease the stresses to allow 10,000 passes of the load wheel before the structure failed. Two parameters, wheel load and tire pressure, were known. The test wheel was loaded to the maximum allowable load (800 lb) for the tire, and the tire was inflated to 32 psi, which is the maximum allowable tire pressure for the tire. The bearing strength of the soaked soil subgrade was assumed to be 3 CBR. Two methods were used to calculate the required thickness of cover: (a) CE flexible pavement design criteria called for a 5.1-in. thickness and (b) Boussinesq's theory of stress distribution for a uniformly loaded circular area called for a 5.0-in. thickness. Therefore, a cover thickness of 5 in. was used.

### Test Equipment

39. A model l^ad cart on which a s all aircraft tire was mounted and a

soil test box (Photo 1) were used to test the pavement systems. A steel frame housed the load cart to prevent side movement as the cart moved back and forth. The steel frame and load cart could be maneuvered into three positions over the soil box for traffic test purposes. The load cart was moved back and forth for tracking purposes by a force generated by an air cylinder on a ram that moved through a maximum travel distance of 24 in. The aircraft tire mounted on the load cart was a 5.00-5, 4-ply tire which was inflated to its maximum pressure of 32 psi. The 800-lb maximum allowable load for the tire was positioned on the load cart. The contact area for the loaded wheel was 20.7 sq in. A side view of the lower portion of the tire, the box collar, and the soil test box is shown in Photo 2. The inside dimensions of the soil test box which contained compacted subgrade material were 36 in. long by 30 in. wide by 12 in. deep. Positioned and clamped with C-clamps to the top of the soil test box, the collar confined the base course material. When a geotextile was tested, it was positioned between the top of the soil test box and the bottom of the collar. Test data were obtained at the midpoint of the traffic lane so that upheaval occurring at the ends of the lane would not influence the results. The test apparatus was capable of applying 4000-5000 passes of the load tire on a traffic lane in an 8-hr period.

## Materials

### Soil

40. A clay (CL)* was used as the subgrade material for the tests. The liquid limit of the clay was 30 and the plastic limit was 21. The gradation curve for the clay is shown in Plate 1. Preweighed amounts of clay were placed in four lifts in the 12-in.-deep soil test box. After each lift was placed, it was compacted with a hand tamper. Samples of clay were obtained during the placement and compaction processes so that the moisture content of the material could be determined. The density of the compacted clay was calculated by dividing the weight of the clay placed in the soil test box by the volume of the test box. After compaction, the moisture content and dry density of the clay were also determined by the direct transmission techniques while using a Troxler Nuclear Densitometer. Comparison of the moisture and density results obtained by the two methods indicated a difference of 1 to

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* Classified by the Unified Soil Classification System (USCS).

1-1/2 percent. Since the results determined by the two methods varied insignificantly and the nuclear densitometer method disturbed less material, all subsequent moisture and density determinations were obtained with the nuclear densitometer. Surface CBR values were estimated based on measurements obtained with an airfield cone penetrometer. Moisture contents, dry densities, and surface CBR (inferred from an airfield cone penetrometer) data obtained before and after each test are shown in Table 1.

41. Crushed limestone which had a maximum aggregate size of 3/4 in. was used as the base course material. The gradation curve labeled 2 in Plate 1 represented the gradation of the aggregate used in test 1. The aggregate used in tests 2 and 3 are represented by the curve labeled 3 in Plate 1. The crushed limestone was placed and compacted in two lifts in the 6-in.-deep collar which was positioned and clamped to the top of the soil test box. Moisture and dry densities were obtained with a Troxler Nuclear Densitometer (Table 1).

Membrane

42. Four layers of a neoprene-coated nylon membrane surfacing were placed on top of the aggregate base course for use as a wearing surface for the pneumatic tire. The layers were bonded together, one on top of the other, with a synthetic rubber-based adhesive. The total thickness and weight of these layers were 3/16 in. and 14.5 lb/sq yd, respectively.

Geotextile

43. One geotextile was tested as a separator between the soil subgrade and aggregate base course. The geotextile was a nonwoven, needle-punched, spun-bonded, polypropylene fabric. The physical properties of the geotextile are shown in Table 2. This geotextile, which had an EOS value of 80 to 100, did not meet the filter criteria listed in paragraph 17 and was not expected to reduce the migration of subgrade fines into the aggregate base course. However, it was included as a test item because it can eliminate the penetration of aggregate particles into the subgrade. Other geotextiles that possessed EOS values of 140 to 170, 200 to 230, and 230 to 325 were scheduled to be tested but were not tested due to funding limitations. The latter two geotextiles met the filter criteria listed in paragraph 17.

## Test Procedures

44. Performance of the geotextile was determined by trafficking the

loaded pneumatic tire on a prepared subgrade/aggregate system and comparing the results of these traffic tests with results of tests conducted on a subgrade/geotextile/aggregate system. The general procedures for conducting the tests are described below. Clay soil, which was used as the subgrade material, was placed in the 12-in.-deep soil test box in four lifts. Each lift was compacted by hand tamping to produce a desired density. After the fourth lift of clay was placed and compacted, it was screeded with a long straight board so the surface of the subgrade would be flat and level with the top of the test box. At this point, the moisture content and density of the soil subgrade were determined. A 33- by 39-in. sample of geotextile was positioned on the subgrade to overlap the inside edges of the test box by 1-1/2 in. on all four sides. If a test were conducted without using a geotextile, no geotextile was positioned on the subgrade. The 6-in.-deep collar used to contain the aggregate base course was placed on the test box and clamped in place. Photo 3 shows the collar placed on top of a geotextile and clamped to the test box. The aggregate base course material was then placed inside the collar, compacted, and leveled, and moisture content and density determinations were made. Preparation of the pavement system was completed by placing the membrane wearing surface on the aggregate base course (Photo 4). After the membrane surfacing was placed, the steel frame and load cart were rolled into position, and the 800-lb load was placed on the load cart (Photo 1).

45. Traffic was initially applied to the subgrade/aggregate or subgrade/geotextile/aggregate system when the system was dry. Then the system was soaked with water and additional passes of the load wheel were applied to the system. Ten thousand passes of the load wheel were applied to each dry pavement system. Due to the slow development of rutting during dry tests, rut depth measurements were taken at the 500-pass level and each 1,000-pass level thereafter. The membrane surfacing was removed before rut measurements were taken to obtain an accurate value. The rut depth was always measured at the midpoint of the traffic lane. After 10,000 passes of the load wheel were completed on the dry system, the top 1 to 2 in. of base course material was reworked, compacted, and leveled. Water was sprinkled over the entire area of the base course until the water level rose to 1/4 in. of the top of the collar. The water was maintained at this level for a period of 3 days to allow the top surface of the soil subgrade to become thoroughly wet. Load tire traffic was applied to the pavement system after it had soaked for 3 days. No

additional water was added during the traffic period. Rut depths were measured at each 100-pass increment for the first 1,000 passes and at 1,000-pass increments thereafter. Traffic was discontinued when upheaval became so great that the bottom of the load cart began dragging on the upheaved aggregate. After traffic was stopped, the rut depth and a cross section of the surface of the system were obtained. The aggregate was carefully removed to expose the geotextile or subgrade surface. After inspection of the geotextile and/or subgrade, rut depths and cross sections were obtained, and then the moisture content, density, and bearing strength of the subgrade were determined.

## Test Results

### Test 1

46. During this test, no geotextile separator was used between the subgrade and base course material. Gradation curves for the clay (CL) used for the subgrade material and the crushed limestone used for the base course material are labeled 1 and 2, respectively, in Plate 1. The load tire was trafficked on two parallel lanes. The tire first traversed back and forth 10,000 times on lane 1; then the load cart was moved over 11 in., and 10,000 passes were trafficked on lane 2. Rut depths developed gradually during the first 2,000 passes to 3/16 in. and 1/4 in. in lanes 1 and 2, respectively, and then remained at these depths for the next 8,000 passes (Plate 2). Photo 5 shows the surface of the base course after 10,000 passes of the load tire were applied to each lane, and Plate 3 shows a cross section of both lanes. As shown in the above-mentioned photograph and plate, very little permanent deformation or upheaval occurred in either traffic lane.

47. After reworking and soaking the base course for 3 days, traffic began in lane 1. Rutting of the pavement system increased rapidly to 1-11/16 in. during the first 500 passes of the load tire, and then increased 1/16 in. during the next 200 passes. From the 700- to the 1,000-pass level, no increase in rut depth was detected. A plot of rut development during this test is shown in Plate 2. Traffic was discontinued after 1,000 passes because no additional rutting occurred during the last 300 passes. This seemed to follow the trend of rut development that occurred during the dry tests. At the 600-pass level, fine soil particle migration from the subgrade was evident because water puddled 3/8 in. deep in the rut was dirty. Only 200 passes of the load tire were

trafficked in lane 2. At this point, the upheaval, which was 2-3/8 in. high, had begun to spill over the side of the collar and the bottom of the load cart began dragging on top of the upheaved material. Rutting in this lane increased rapidly to 2 in. after 200 passes (Plate 2). A cross section of the aggregate surface after traffic was completed on the wet system is shown in Plate 3.

48. After traffic was completed on the wet pavement system, one-half of the aggregate was removed. Then the subgrade was inspected, cross sections of the surface of the subgrade were obtained, fine soil particle migration was determined, and soil data were obtained. Inspection of the surface of the subgrade revealed that 3/4-in. pieces of aggregate had penetrated into the subgrade in the rutted areas to depths of 1/4 in. and some of the smaller aggregate was completely embedded into the subgrade. A cross section of the subgrade surface is shown in Plate 3. Only 1/8 in. of deformation was measured in each traffic lane and no upheaval was detected. Visual inspection of the exposed vertical face of the aggregate base course revealed that the aggregate was contaminated with soil particles to 1-5/16 in. of the top of the surface of the base course. As shown in Table 1, the dry density and bearing strength of the soil subgrade decreased and the moisture content of both the base course material and the subgrade material increased during the test.

Test 2

49. As in test 1, no geotextile separator was used between the subgrade and base course materials. Gradation curves for the clay (CL) subgrade material and the crushed limestone base course material are shown in Plate 1 and are labeled 1 and 3, respectively. During this test, the load tire was trafficked in only one lane which was located 15 in. from the side edge of the pavement system. As the load tire trafficked on the dry system, rutting of the base course developed rapidly to 9/16 in. during the first 500 passes and then gradually increased to 11/16 in. at the 2,000-pass level. No additional rutting occurred during the next 8,000 passes. A plot of rut depth versus passes is shown in Plate 2. A cross section of the dry aggregate surface after 10,000 passes of the load tire is shown in Plate 4. As shown in the cross section, 1/4 in. of upheaval developed on each side of the traffic lane.

50. After the base course was reworked and soaked for 3 days, traffic was applied to the pavement system. As shown in Plate 2, rutting of the system developed to 2-5/8 in. after only 426 passes of the load tire. At this

point, traffic was stopped because the bottom of the load plate which supported the 800-lb load was striking the top of the load cart. Because of the design of the equipment, this caused less than 800 lb to be applied to the load tire. A cross section of the surface of the base course is shown in Plate 4. A maximum height of 1-1/4 in. of upheaval developed during this test. As shown in Photo 6, water was puddled 3/4 in. deep in the traffic lane. The water was clear, which indicated that subgrade soil particles had not migrated to the bottom level of the rut.

51. One-half of the aggregate was removed from the pavement system; then the subgrade was inspected, cross sections of the subgrade surface were obtained, fine soil particle migration was determined, and soil data were obtained. Photo 7 shows the vertical face of the aggregate and the surface of the subgrade after one-half of the aggregate was removed. Three-quarter-inch pieces of aggregate penetrated into the subgrade. Measurements of the penetrations ranged from 3/8 to 1/2 in. Most of the smaller size aggregate was completely embedded into the surface of the subgrade. A cross section of the surface of the subgrade is shown in Plate 4. The subgrade was rutted to a depth of 1 in. and the maximum upheaval was measured to be 1-3/8 in. Inspection of the vertical face of the aggregate revealed that the aggregate was contaminated with soil particles to within 2-7/8 in. of the top of the surface of the base course. The dry density and bearing strength of the subgrade decreased and the moisture content of the subgrade and base course increased during the test (Table 1).

Test 3

52. The geotextile described in paragraph 41 was used to separate the base course material from the subgrade during this test. Gradations of the materials used for the subgrade and base course were the same as those used in test 2 in which only one lane was trafficked with the load tire. The lane was located 15 in. from the side of the pavement system. Rut development of the dry system during 10,000 passes of the load tire is shown in Plate 2. After 500 passes of the load tire, the rut was 13/16 in. deep. The depth of rut gradually increased to 15/16 in. during the next 1,500 passes. The rut depth was unchanged from the 2,000- to the 6,000-pass level, but gradually increased to 1-1/16 in. during the next 4,000 passes (Plate 2). A cross section of the dry aggregate surface after 10,000 passes of the load tire is shown in Plate 5. The cross section shows a maximum upheaval of 1/2 in. occurred as the load

tire trafficked on the pavement system. Photo 8 shows the aggregate surface and the rutted traffic lane after traffic was completed on the dry system.

53. As in the two previous tests, traffic was initiated on the wet pavement system after the base course was reworked and soaked for 3 days. A plot of rut development during traffic is shown in Plate 2. Rutting of the system increased at a constant rate during the first 1,000 passes of the load tire and then increased at a lesser rate during the remainder of the test. Traffic was stopped after 7,386 passes because rutting caused the load plate to strike the top of the load cart. After 7,386 passes, the traffic lane was rutted to a depth of 2-1/2 in. A cross section of the surface of the base course after traffic is shown in Plate 5. Upheaval developed to a maximum height of 11/16 in. during this test. Photo 9 shows the surface of the pavement system after traffic was stopped. As shown in this photo, 1/4-in.-deep muddy water was puddled in the traffic lane. Soil particle migration was evident at the 4,000-pass level because water puddled 7/16 in. deep in the traffic lane was dirty.

54. Photo 10 shows the pavement system after one-half of the base course material was removed. Visual inspection and measurements of the vertical face of the base course revealed that soil particles had migrated to within 1-7/8 in. of the top of the base course. The remaining one-half of the base course was removed to inspect the top surface of the geotextile. As shown in Photo 11, the entire top surface of the geotextile was covered with wet soil particles. Shallow indentations caused by large pieces of aggregate were found on the surface of the geotextile. No signs of abrasion of the fibers were noticed. Photo 12 shows the bottom surface of one-half of the geotextile. An area located outside of the traffic lane was not covered with soil particles. Since the top surface of the geotextile was completely covered with soil particles and the bottom surface was not, it is assumed that the soil particles migrated upward in the area of the traffic lane and then laterally through the aggregate base course. When the geotextile was removed from the subgrade (Photo 13), indentations approximately 1/16 in. deep were found in the traffic lane area. No particles of crushed limestone were found on the surface of the subgrade. As the cross section of the subgrade surface shows in Plate 5, the subgrade rutted to a depth of 5/16 of an inch, and no upheaval occurred. Table 1 shows the dry density and the bearing strength of the subgrade material decreased while the moisture content increased during the test.

## Tests and Test Results

55. During the first test, while trafficking the soaked pavement system, the upheaval became so great in lane 2 that traffic was discontinued. The upheaved base course was forced over the top of the 6-in. collar and the bottom of the load cart began dragging the top of the material. It became evident that the 30-in.-wide test area was not wide enough for two traffic lanes. Therefore, tests 2 and 3 were conducted with one traffic lane, which was located at the center of the 30-in.-wide test area. It was also believed that the upheaval was caused by the amount of fines used in the crushed limestone in test 1. When the fines became wet, they lubricated the larger pieces of aggregate and caused lateral movement of the aggregate. Therefore, the smaller fines (those passing the No. 100 sieve) were removed from the aggregate mix used in tests 2 and 3. The gradation of the two base course materials is shown in Plate 1. During tests 2 and 3, no upheaval problems were experienced.

56. Since test procedures and materials were altered after test 1, the results of tests 2 and 3 only were compared. Also, since a separator is needed mainly when there is a wet or saturated condition, the results of tests conducted on the soaked systems were compared. Results of the three tests are shown in Table 3. Comparison of the results indicates that the geotextile provided a separator medium and extended the life of the pavement system. The aggregate/geotextile/subgrade system withstood more than 17 times the amount of traffic applied to the aggregate/subgrade system (7368 passes versus 426 passes). The aggregate/geotextile/subgrade system rutted less (1/8 in.) and upheaved less (9/16 in.) than the aggregate/subgrade system. Comparison of subgrade conditions after the tests also confirms that the geotextile provided a separator mechanism. Maximum rutting of the subgrade during test 2 was more than three times greater than the rutting during test 3. No upheaval occurred during test 3, whereas 1-3/8 in. of upheaval was measured after test 2. The geotextile restricted the penetration of aggregate into the subgrade since the aggregate penetration was six to eight times greater during test 2 than during test 3. Even though 17 times more traffic was applied to this pavement system, the subgrade soil particle migration was 1 in. greater during test 3.

57. The geotextile failed to prevent the subgrade fines from migrating into the aggregate base course, but it did improve the performance of the pavement system. The geotextile was not expected to be an effective filter

because the $D_{85}$ of the subgrade material was smaller than the EOS of the fabric. Therefore, the fabric did not meet the filter criteria listed in paragraph 16. Results of test 3 confirmed the ineffectiveness of the fabric as a filter since soil particles rose to a height of 4-1/8 in. when traffic was applied to the soaked pavement system. Despite the geotextile's failure as a filter, comparison of results of tests 2 and 3 showed that the geotextile improved the performance of the pavement system.

## PART V: LITERATURE SUMMARY AND CONCLUSIONS AND RECOMMENDATIONS

### Literature Summary

58. The following is a summary of key points concerning the use of geotextiles as a separating medium between aggregate base courses or ballast and soil subgrades obtained from the literature:

a. The primary function of a geotextile used as a separator is to ensure that the roadway or railway structure remains as originally designed during its service life.

b. A geotextile can transmit pore water.

c. A geotextile can stop the penetration of aggregate into the subgrade.

d. Nonwoven, needle-punched geotextiles provide better separator mediums than other types of geotextiles.

e. The minimum weight of a geotextile used as a separator is 4 oz/sq yd.

f. Geotextiles can resist the puncture and abrasive forces that occur when aggregate is placed and compacted.

g. The EOS of a geotextile is dependent on the grain size of the subgrade material. A geotextile's EOS is less than or equal to the $D_{85}$ of the soil when the soil is a sand or coarser. Fabrics cannot be used when 85 percent or more (by weight) of the soil is finer than the No. 200 sieve.

h. Polyester fabrics are resistant to ultraviolet rays, whereas polypropylene fabrics are not.

i. Abrasive damage of geotextiles caused by full-depth tamping of ballast is minimized when geotextiles are placed 10 to 12 in. below the bottom of crossties.

### Conclusions from Experimental Program

59. Conclusions based on the experimental investigation are as follows:

a. The pneumatic-tired testing equipment provides a method of evaluating geotextiles used as separators in roadway construction.

b. The addition of the geotextile substantially improved the number of coverages to failure when the pavement system was soaked. In the unsoaked system, performance of the system without the geotextiles was slightly better.

c. Rutting of the soaked pavement system was considerably greater than rutting of the unsoaked system.

d. The geotextile prevented base course penetration into the subgrade.

e. The geotextile failed to prevent wet subgrade material migration into the base course but the geotextile improved the performance of the pavement system.

f. The 12-oz/sq yd nonwoven, needle-punched, spun-bonded, polypropylene geotextile located 5 in. below the 800-lb, 20.7-sq-in. contact area wheel load was unchanged after 17,368 traffic repetitions in spite of direct contact with 3/4-in. maximum particle size coarse aggregate.

## Recommendations

60. The following recommendations are made:

a. A geotextile used as a separator should be fabricated from a nonwoven, needle-punched, polyester fabric.

b. The pneumatic-tired testing equipment should be used to evaluate currently available geotextiles that manufacturers recommend as separators.

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Table 1

Soil and Base Course Data

| Test No. | Subgrade | | | | | | Base Course | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Before Testing | | | After Traffic* | | | Before Traffic | | After Traffic | |
| | Density lb/cu ft | Moisture Content, % | Surface CBR, % | Density lb/cu ft | Moisture Content, % | Surface CBR, % | Density lb/cu ft | Moisture Content, % | Density lb/cu ft | Moisture Content, % |
| 1 | 109.3 | 15.8 | >18** | 107.4 | 17.2 | 6.1 | 138.0 | 0.2 | - | 4.3 |
| 2 | 110.8 | 14.6 | >18 | 103.0 | 20.0 | 1.2 | 131.5 | 0.4 | - | † |
| 3 | 107.9 | 11.3 | >18 | 102.9 | 20.3 | 1.3 | 131.5 | 0.4 | - | † |

* Obtained in bottom of rut.
** Exceeded capacity of airfield cone penetrometer.
† Water puddled in rut.

Table 2

Physical Properties of Geotextile

| Test and Test Method | Property |
|---|---|
| Weight, oz/sq yd<br>ASTM D 1910 | 12 |
| Thickness, mils<br>ASTM D 1777 | 100 |
| Grab tensile, lb/in.<br>ASTM D 1682 | 240 |
| Strip tensile, lb/in.<br>ASTM D 1682 | 100 |
| Elongation, percent<br>ASTM D 1682 | 175 |
| Trapezoid tear, lb<br>ASTM D 2263 | 85 |
| Mullen burst, psi<br>ASTM D 231 | 350 |
| EOS, U. S. Standard Sieve No.<br>CW-02215 | 80-100 |

Table 3

Comparison of Test Results

| Test Condition | Total Passes of Load Tire | Pavement System | | Soil Subgrade | | | |
|---|---|---|---|---|---|---|---|
| | | Maximum Rut Depth in. | Maximum Upheaval in. | Maximum Rut Depth in. | Maximum Upheaval in. | Aggregate Penetration in. | Soil Particle Migration Height, in. |
| **Test 1** | | | | | | | |
| Lane 1 | | | | | | | |
| Dry | 10,000 | 3/16 | 1/8 | | | | |
| Wet | 1,000 | 1-3/4 | 5/8 | 1/8 | 0 | 1/4 | 4-11/16 |
| Lane 2 | | | | | | | |
| Dry | 10,000 | 1/4 | 1/8 | | | | |
| Wet | 200 | 2 | 2-3/8 | 1/8 | 0 | 1/4 | 4-11/16 |
| **Test 2** | | | | | | | |
| Dry | 10,000 | 11/16 | 1/4 | | | | |
| Wet | 426 | 2-5/8 | 1-1/4 | 1 | 1-3/8 | 3/8-1/2 | 3-1/8 |
| **Test 3** | | | | | | | |
| Dry | 10,000 | 1-1/16 | 1/2 | | | | |
| Wet | 7,368 | 2-1/2 | 11/16 | 5/16 | 0 | 1/16 | 4-1/8 |

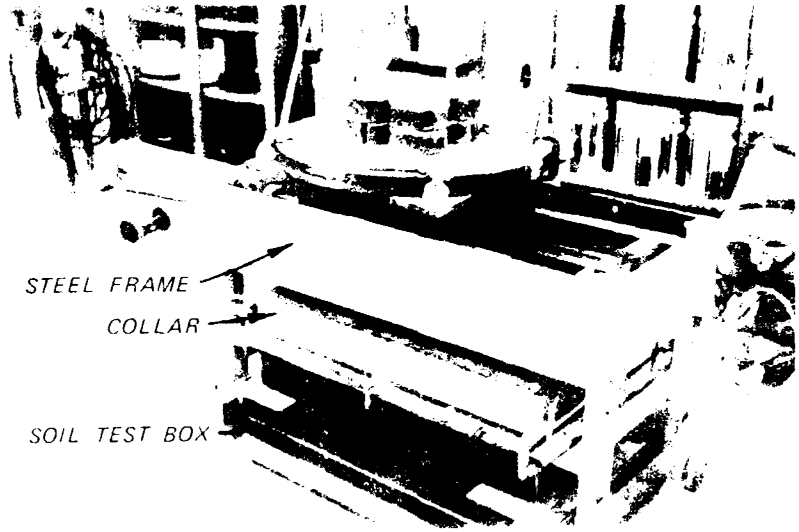



Photo 1. Model load cart for testing pavement systems

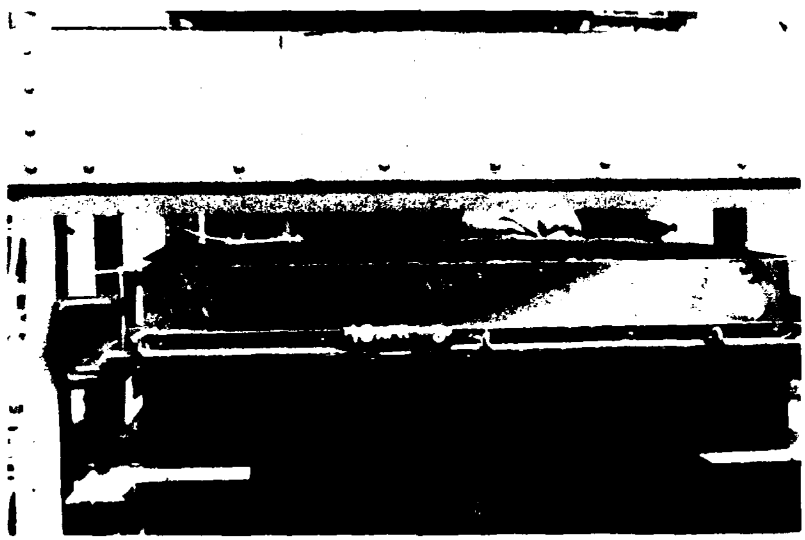


Photo 2. Side view of load tire

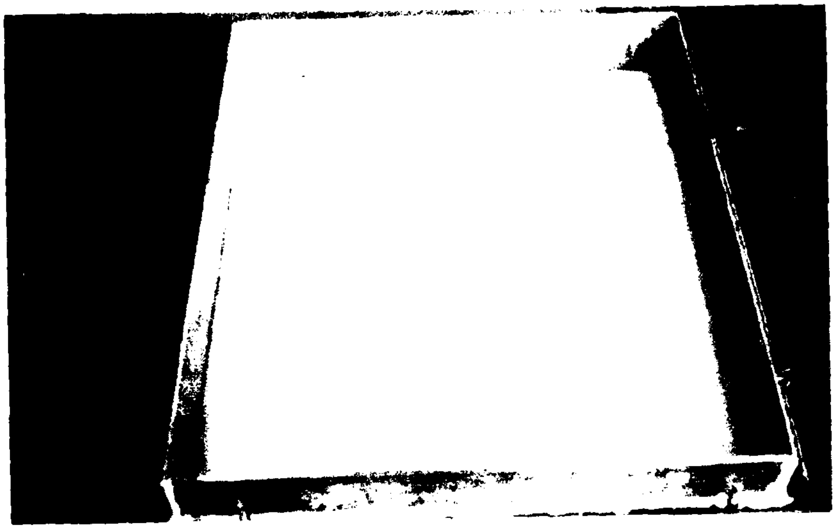


Photo 3. Six-inch-deep collar clamped in position

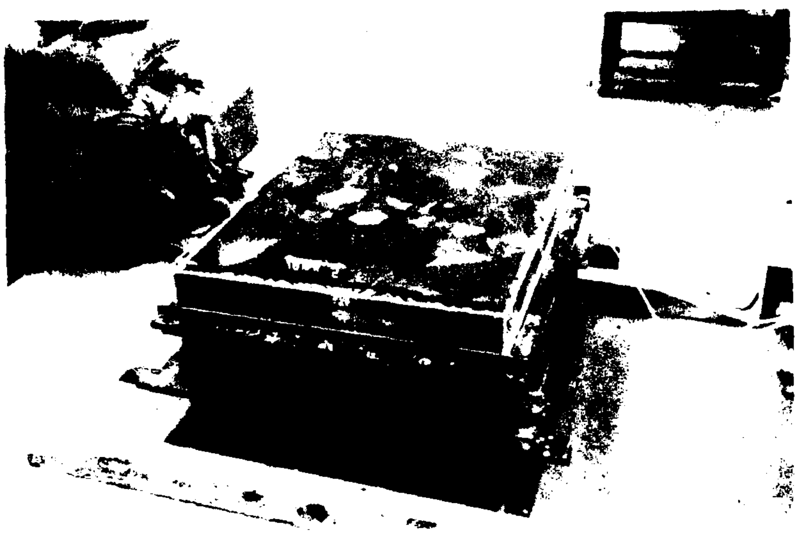


Photo 4. Pavement system prior to test

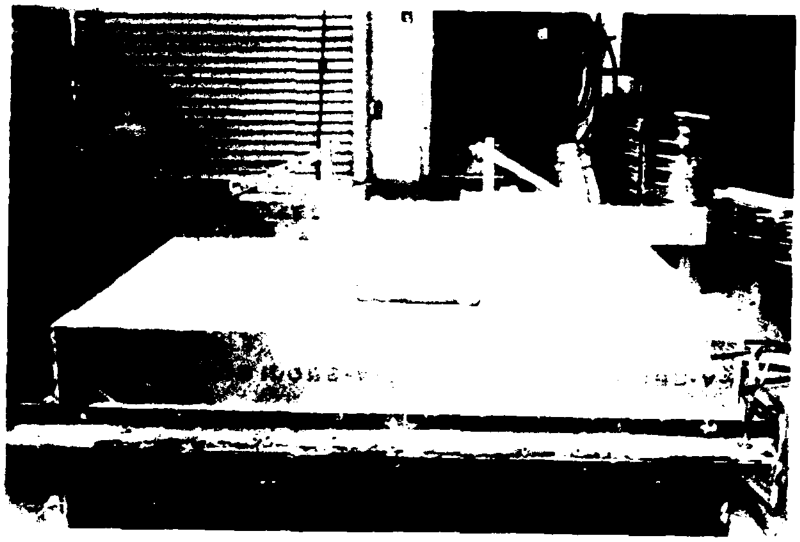


Photo 5. Surface of base course after 10,000 passes, test 1

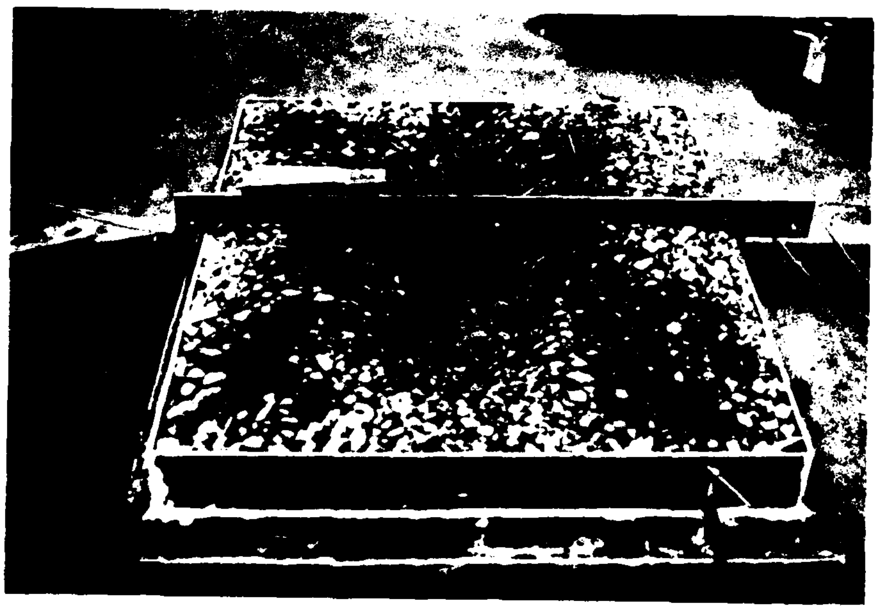


Photo 6. Rutted traffic lane after 426 passes of load tire, test 2

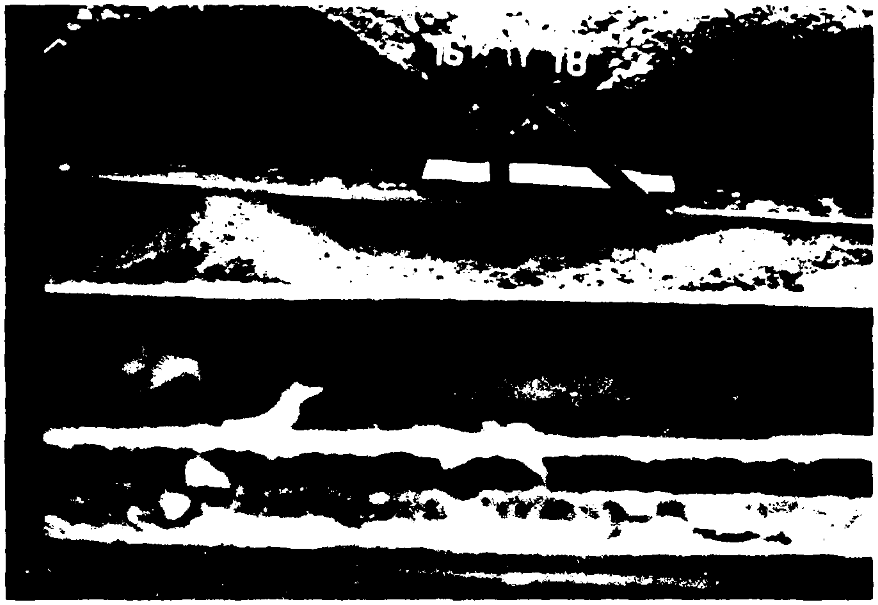


Photo 7. Surface of subgrade after wet tests, test 2

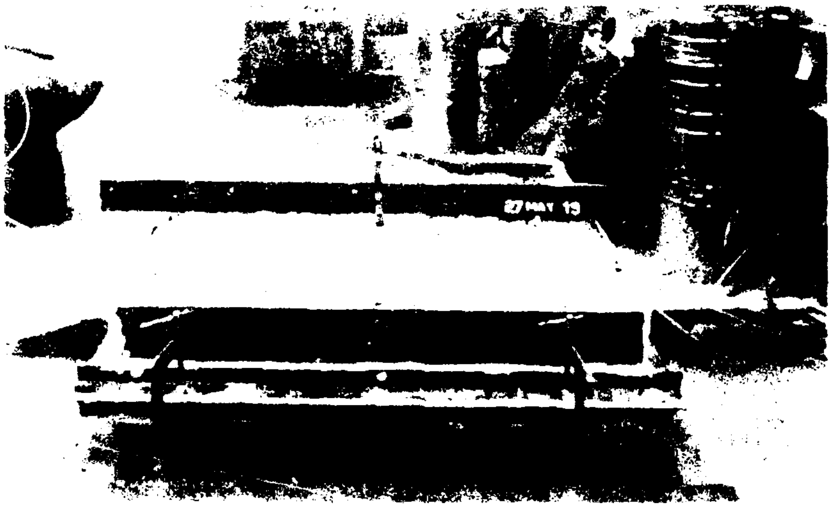


Photo 8. Surface of base course after dry test, test 3

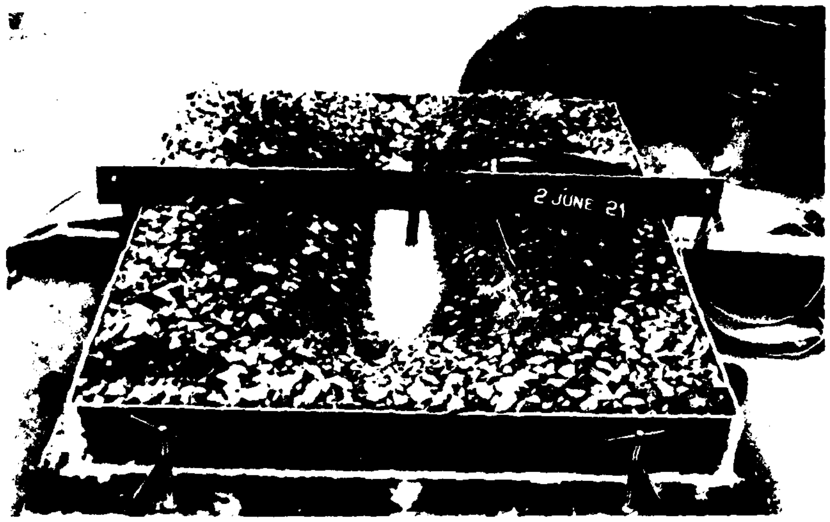



Photo 9. Surface of base course after wet tests, test 3

Photo 10. One-half of base course material removed, test 3

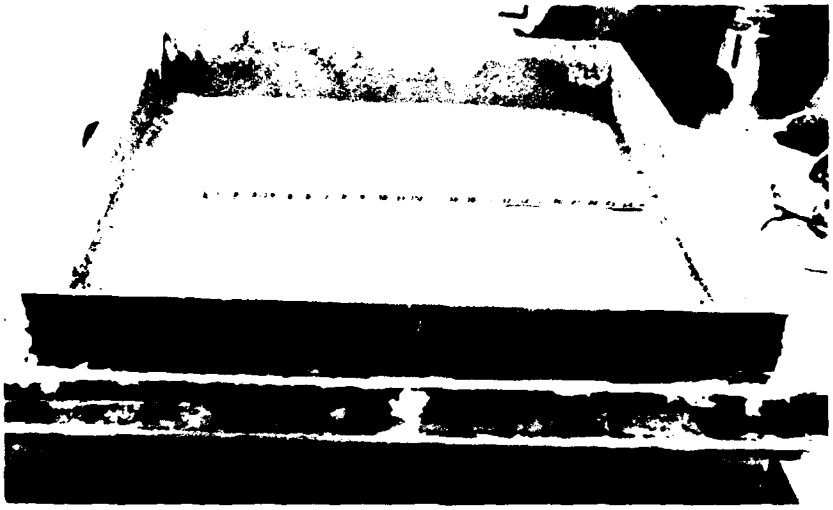


Photo 11. Top of geotextile after base course was removed, test 3

Photo 12. Bottom of one-half of geotextile

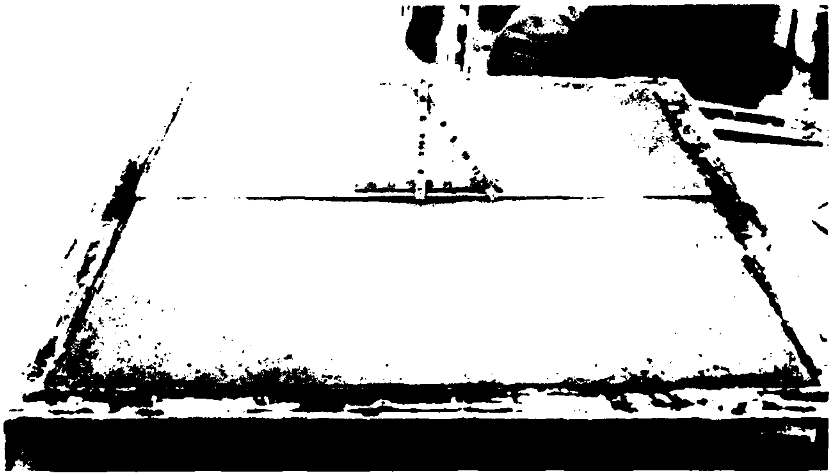
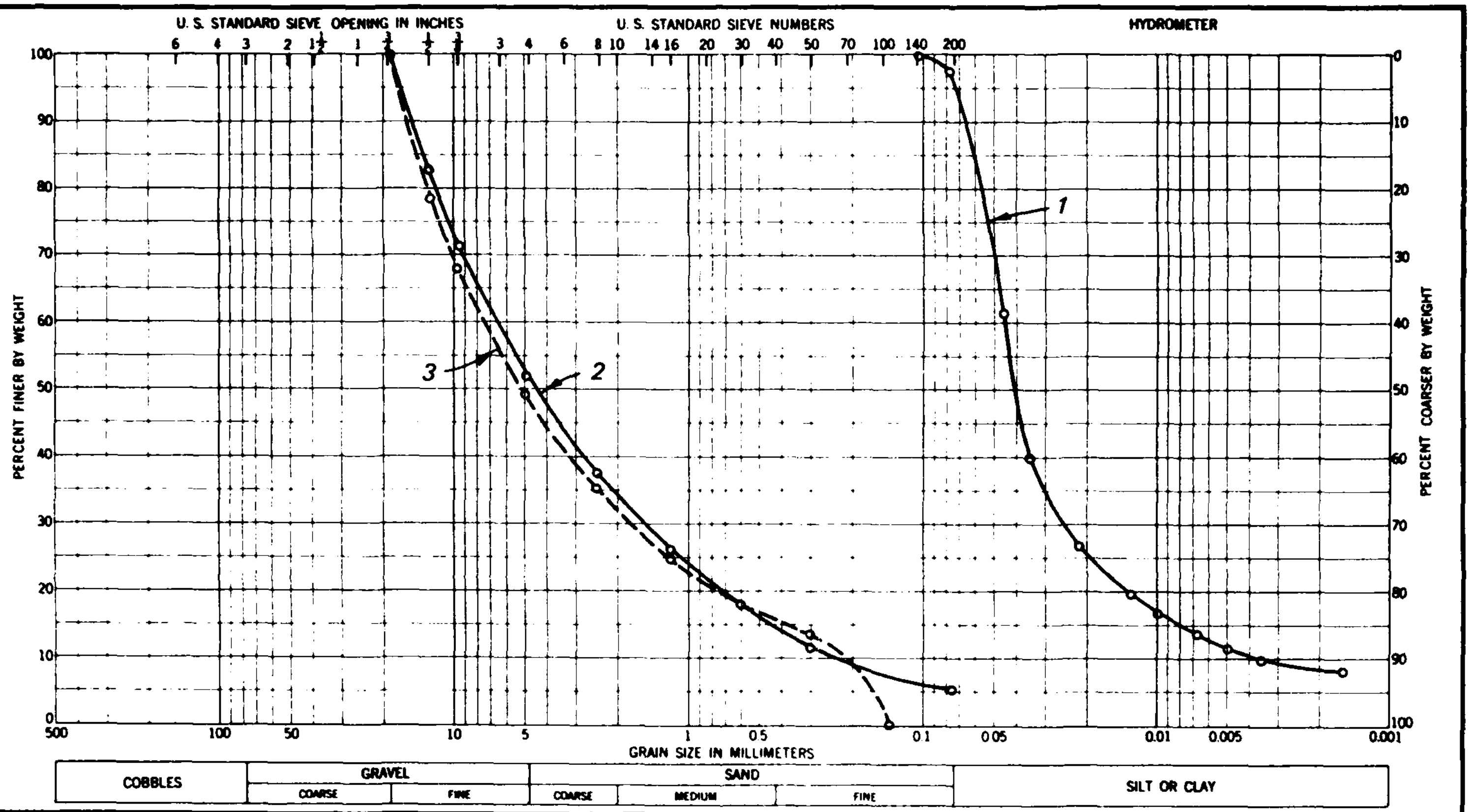


Photo 13. Surface of subgrade after wet tests, test 3




| Sample No. | Elev or Depth | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| 1 | SUBGRADE | Clay (CL) | | 30 | 21 | 9 |
| 2 | BASE, TEST 1 | CRUSHED LIMESTONE | | | | |
| 3 | BASE, TESTS 2 & 3 | CRUSHED LIMESTONE | | | | |

# GRADATION CURVES

ENG FORM 1 MAY 63 2087

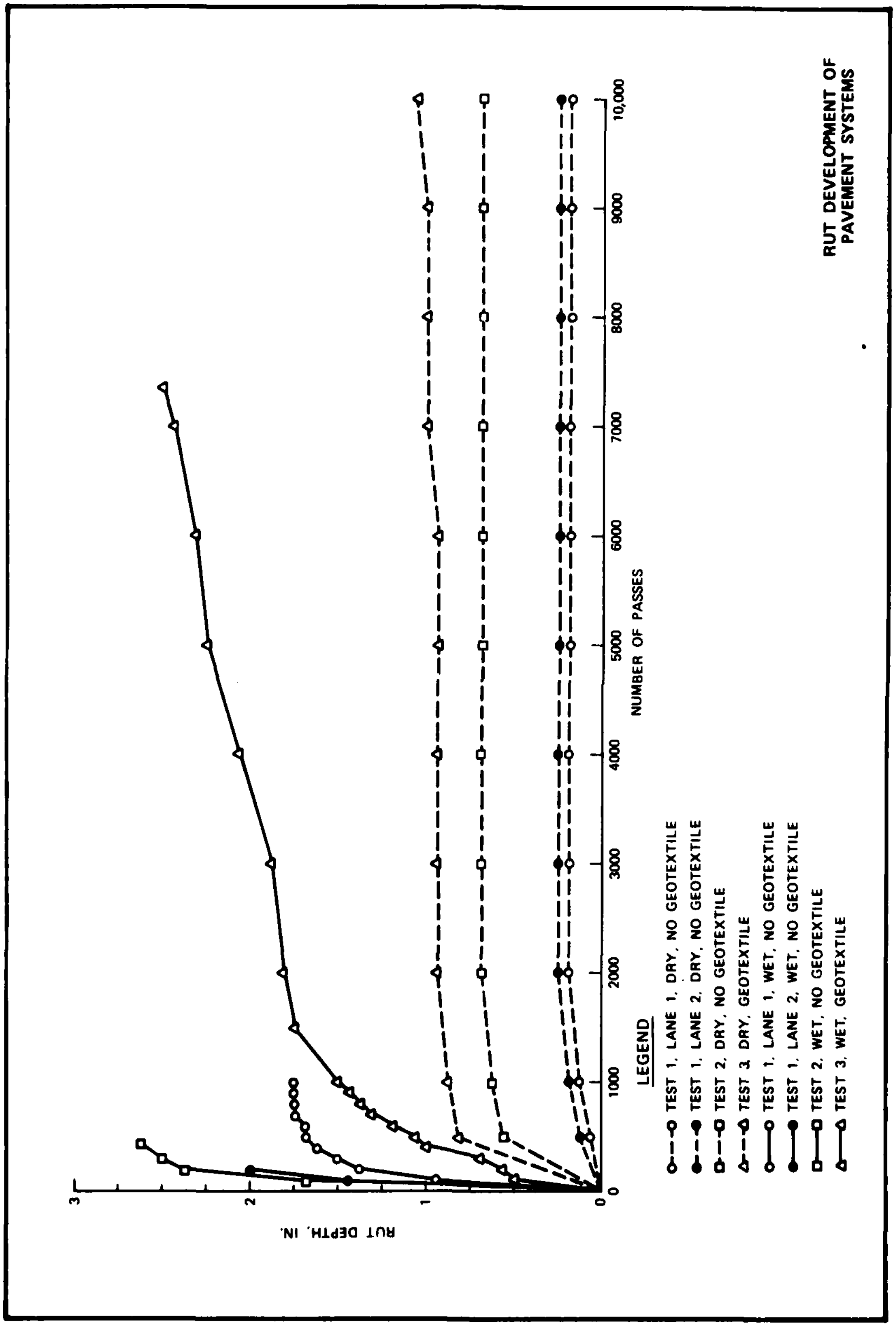
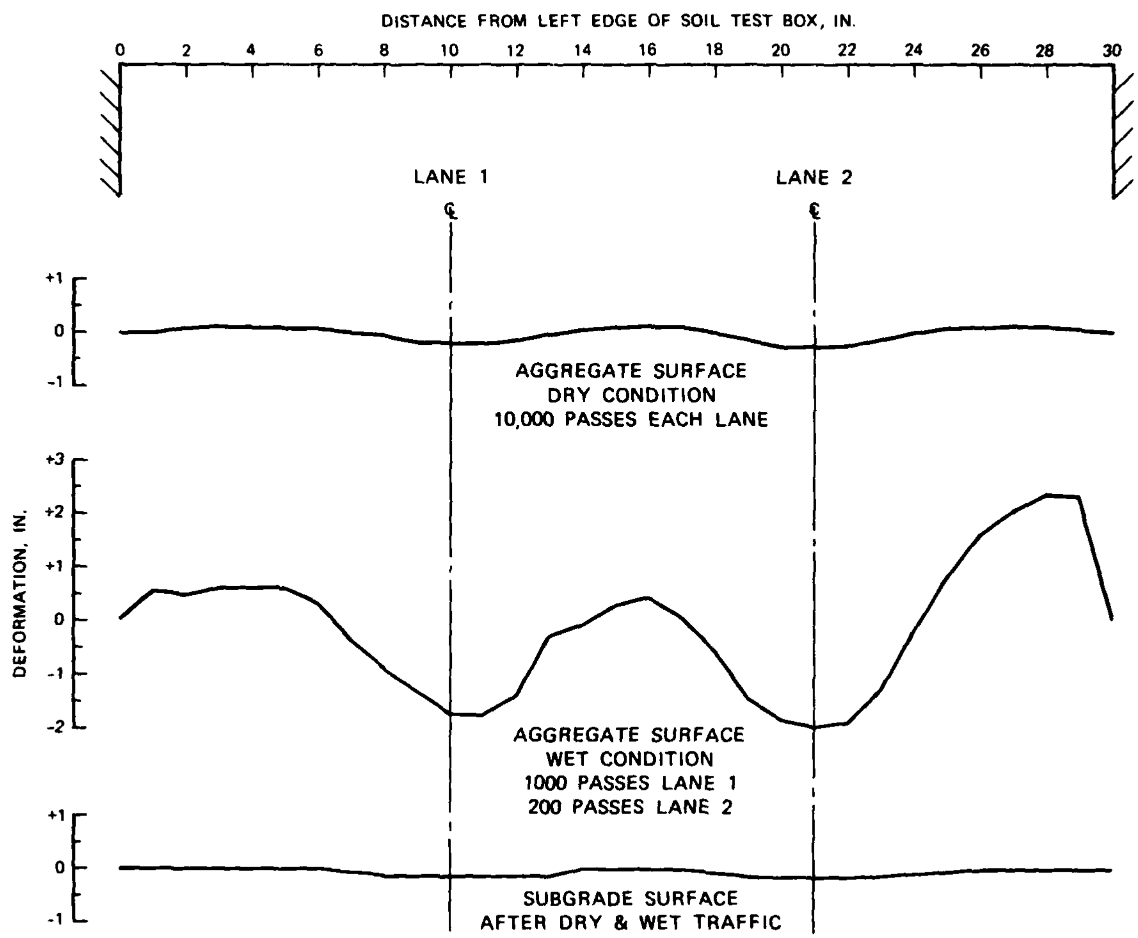

RUT DEVELOPMENT OF
PAVEMENT SYSTEMS
RUT DEPTH, IN.
NUMBER OF PASSES
0
1
2
3
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
LEGEND
TEST 1, LANE 1, DRY, NO GEOTEXTILE
TEST 1, LANE 2, DRY, NO GEOTEXTILE
TEST 2, DRY, NO GEOTEXTILE
TEST 3, DRY, GEOTEXTILE
TEST 1, LANE 1, WET, NO GEOTEXTILE
TEST 1, LANE 2, WET, NO GEOTEXTILE
TEST 2, WET, NO GEOTEXTILE
TEST 3, WET, GEOTEXTILE

PLATE 2




TEST 1
CROSS SECTIONS

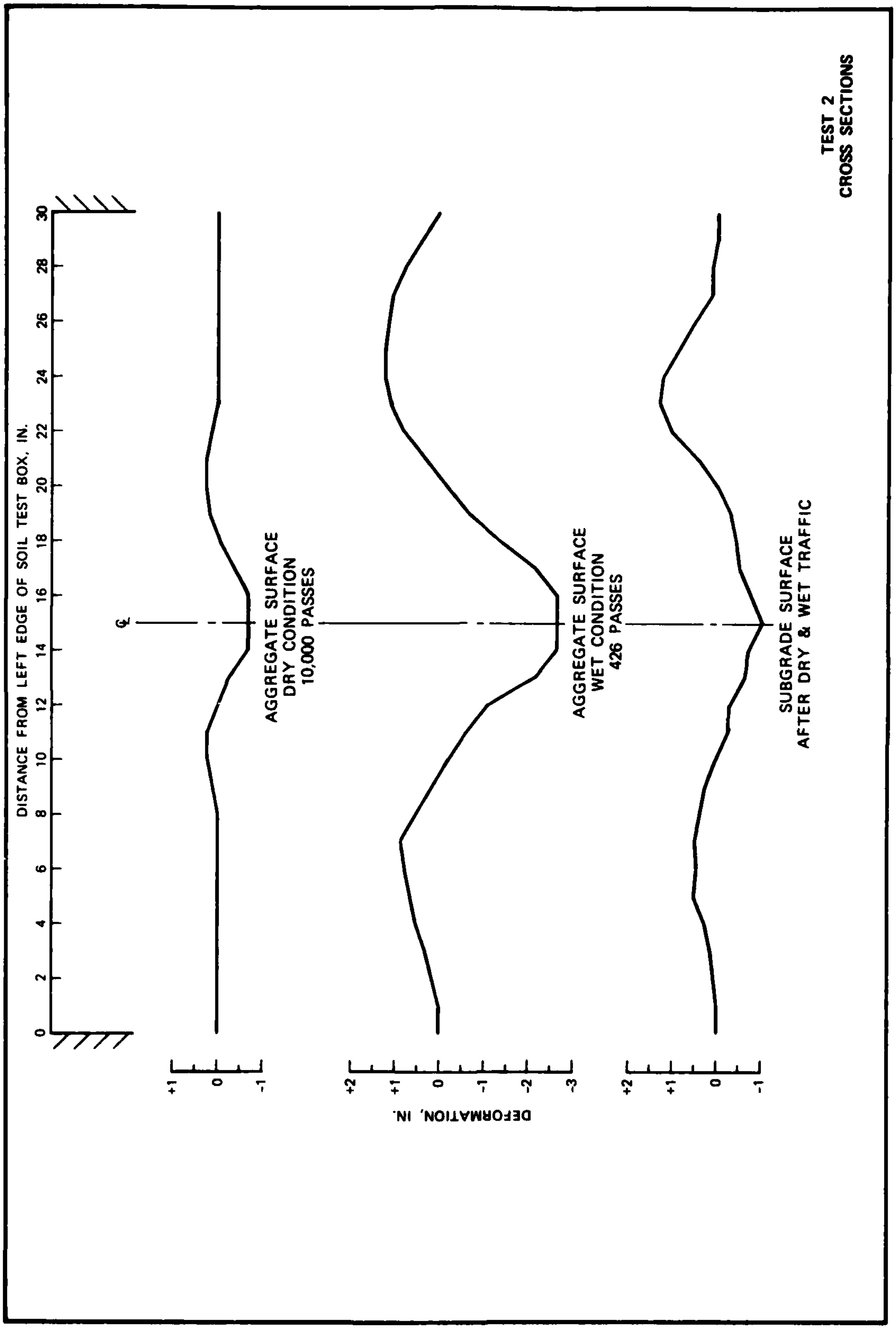
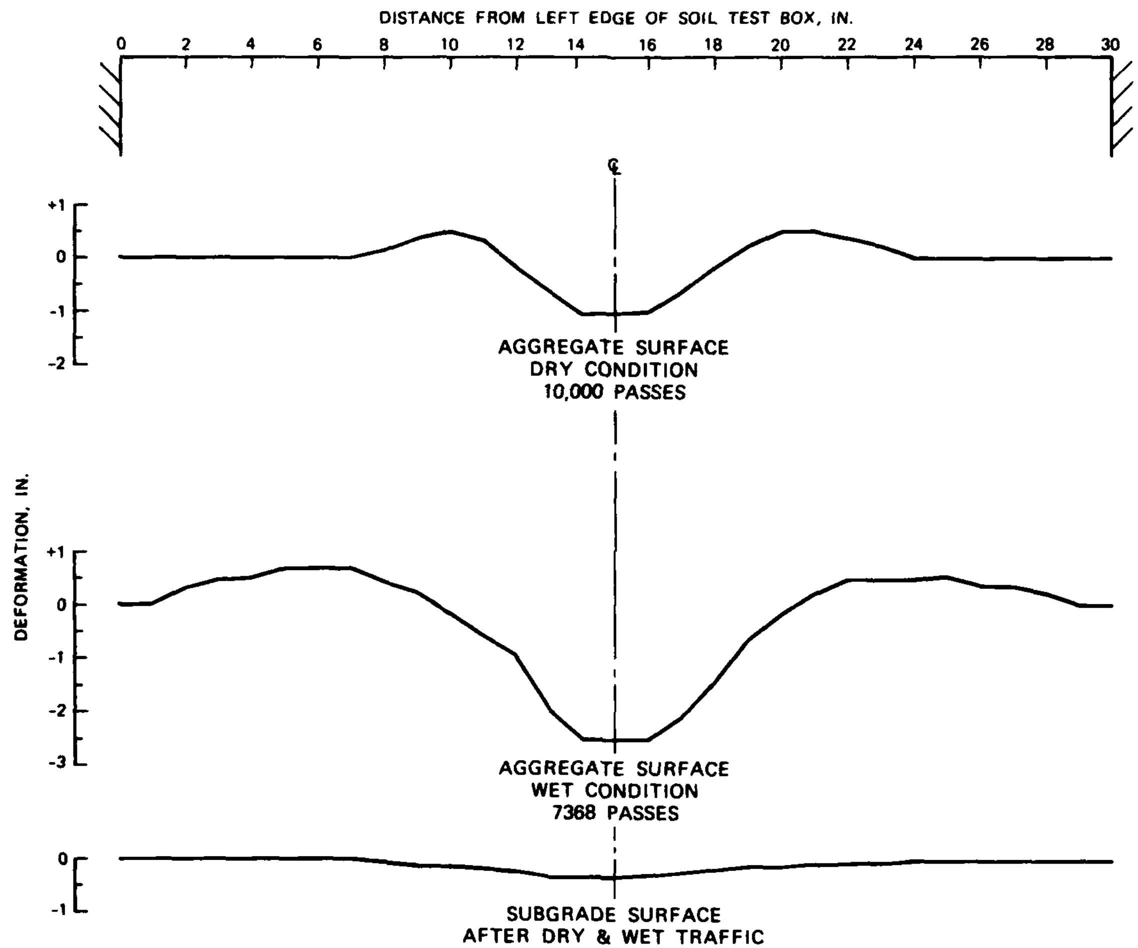

TEST 2
CROSS SECTIONS
DISTANCE FROM LEFT EDGE OF SOIL TEST BOX, IN.
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
℄
AGGREGATE SURFACE
DRY CONDITION
10,000 PASSES
AGGREGATE SURFACE
WET CONDITION
426 PASSES
SUBGRADE SURFACE
AFTER DRY & WET TRAFFIC
DEFORMATION, IN.
+1
0
-1
+2
+1
0
-1
-2
-3
+2
+1
0
-1

PLATE 4




**TEST 3**
**CROSS SECTIONS**

ATE
LMED
-8